Image Surround: Automatic Projector Calibration for Indoor Adaptive Projection

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Abstract. In this paper, we present a system able to calibrate projectors, perform 3D reconstruction and project shadow and textures generated in real-time. The calibration algorithm is based on Heikkila's camera calibration algorithm. It combines Gray coded structured light patterns projection and a RGBD camera. Any projection surface can be used. Intrinsic and extrinsic parameters are computed without a scale factor uncertainty and any prior knowledge about the projector and the projection surface. The projector calibration is used as a basis to augment the scene with information from the RGBD camera. Shadows are generated with lights. Their position is modified in real-time to follow a user position. The 3D reconstruction is based on the Kinect fusion algorithm. The model of scene is used to apply texture on the scene and to generate correct shadows.

Keywords: projection, calibration, tracking, scene augmentation.

1 Introduction

Video projectors are mostly known for their classical use: a projection on a planar screen with the projector located in front of it. The homography integrated in the menu of all new the projectors has enabled to slightly change the projector position but the screen is still a planar surface.

During the last years new developments in video projector calibration arose. With structured light scanning, projection on complex surfaces can be performed [13] but the correction is perfect from only one point of view: the camera. Furthermore, if any object moves, the process has to be restarted.

To provide more capabilities to projectors in terms of projection surface, multiple methods for projector calibration have already been proposed. Audet and Okutomi [2] method provides a good way to calibrate the intrinsic parameters of the projector but it does not solve the problem of the extrinsic calibration. The method uses a planar board to calibrate a camera and a projector at the same time. If the projector is not close to the camera, it is difficult to project on the board and at the same time, put the board in a good position for the

M. Mancas et al. (Eds.): INTETAIN 2013, LNICST 124, pp. 156–162, 2013.

camera detection. A solution is to increase the size of the board but the method becomes less user-friendly.

In [16], Yamazaki et al. presented a method for the geometric calibration of a video projector using an uncalibrated camera and structured light. Nevertheless, the method performs the calibration up to a scalar factor. Moreover, a prior knowledge of the principal point is needed.

With the rise of intelligent TV and social gaming, most of the applications need to provide a visual feedback to the user. Microsoft's Kinect sensor allows to track people easily and to develop intuitive human to computer interactions [5]. Tracking moving objects or people is easier [4,12,9] but to project on them, a full geometric calibration of the projector is required. The need for an easy-to-use projector calibration is growing.

In this paper, we propose a fully automatic method for the geometric calibration of a projector. The process is based on Heikkila's algorithm [7] but it is extended to projector calibration with the use of structured light and a RGB-Depth (RGBD) camera. We apply the calibration to augment a scene with shadows and textures.

The rest of the paper is organised as follows. Section 2 describes the projector model and the projector calibration method. Section 3 gives the results. Section 4 shows how the scene is augmented. Finally, Section 6 concludes the work and gives some perspectives to improve the method.

2 Projector Calibration

The mathematical model of the projector used in this paper is the pinhole model [6]. Indeed, a projector is the same as a camera, the only difference being the light ray direction [10]. This model is represented mathematically by equation 1.

$$x \sim P\ X_{world} = K[R|t]X_{world} \tag{1}$$

In this equation, $x(u, v, 1)$ is the pixel position in the projected 2D image and $X_{world}(X, Y, Z, 1)$ is a 3D position where the pixel x lights up. The matrix K is called the projector calibration matrix. R—t is the coordinate transform from the world coordinate frame to the camera coordinate frame. R is the rotation matrix and t, the translation vector.

The projector calibration needs multiple couples of 3D coordinates and pixel coordinates. We propose to use Heikkila's algorithm [7] to perform the calibration. Heikkila algorithm is based on the direct linear algorithm and does not impose a constraint on the surface to use. A structured light projection gives pixel to pixel correspondences between the projector and the camera, while the use of a RGBD camera gives the 3D coordinates of the projected points. Therefore, couples of 3D and pixels coordinates are retrieved. The proposed method is represented in figure 1.

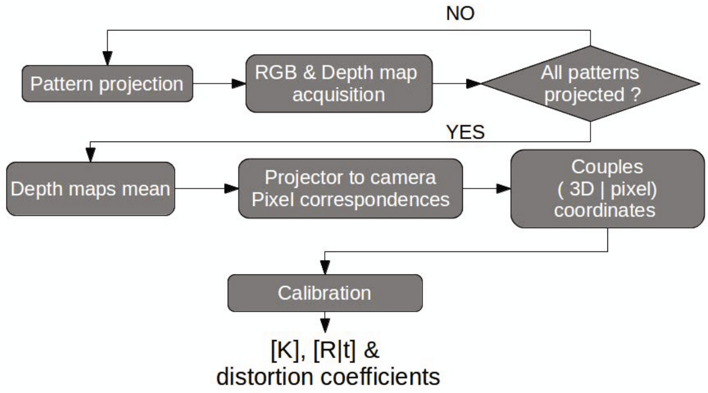

Fig. 1. Calibration process

The process is decomposed in different steps:

1. Project the Gray-coded binary patterns
2. Acquire a RGB and a depth map for each projected pattern
3. Compute the correspondences between the pixel of the projector and the RGBD camera
4. Average the depth maps to eliminate possible noise on the depth mesure
5. Compute the couple of pixel 2D coordinates and its 3D coordinates
6. Apply Heikkila's algotrithm

The method does not impose a planar surface constraint and is fully automated. For more details, the method is further described in [3].

3 Calibration Results

We performed multiple calibrations for different camera positions and for different zooms of the projector. The average reprojection error from multiple calibration tests is presented in the table 1.

Compared to state of the art methods [16,2], the method provides a higher reprojection error. Those high values are explained by:

- the error introduced during the structured light correspondences estimation,
- the error introduced by the RGBD camera,
- Heikkila's algorithm which is less accurate.

Nevertheless, the proposed algorithm has the important advantage to be fully automatic which is not the case of the other methods, and there is no need of any a priori knowledge: only a non planar surface is needed. Those advantages are central in an application which could be used by non specialists in their living room.

Table 1. Average reprojection error RMSE (in pixel)

Average reprojection error	
u	v
2.5368	2.3558

4 Scene Augmentation

It is complex to handle textures and shadows directly in an OpenGL scene. To simplify this process, we used Unity [14] rendering engine. It manages the shadows and textures in real time and simplifies the light management compared to pure OpenGL.

To perform the real-time rendering, the projector is modelled in the virtual world by a perspective projection. The perspective describes a pyramid in which every object is rendered (see Figure 2 [11][1]). Equation 2 provides a way to transform the projector matrix value into a perspective transform.

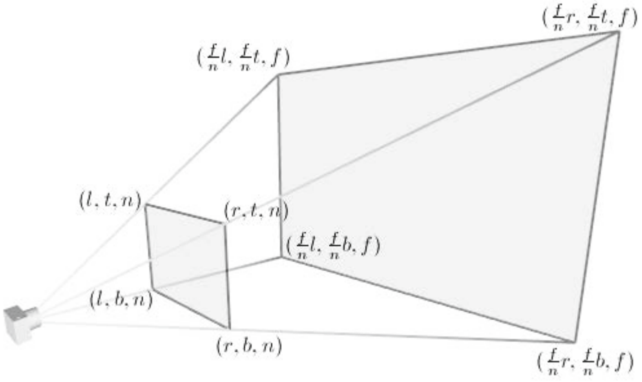

Fig. 2. Calibration process

$$perspective\ transform = \begin{pmatrix} \frac{2n}{r-l} & 0 & \frac{r+l}{r-l} & 0 \\ 0 & \frac{2n}{t-b} & \frac{t+b}{t-b} & 0 \\ 0 & 0 & -\frac{f+n}{f-n} & -\frac{2fn}{f-n} \\ 0 & 0 & -1 & 0 \end{pmatrix} \qquad (2)$$

Equation 2 uses six parameters: near (n), far (f), left (l), right (r), top (t), bottom (b). The left (right) is the position of the left (right) plane of the pyramid along the x axis. The top (bottom) is the position of the top (bottom) plane of the pyramid along the y axis. Those values are obtained from the K matrix (f_u,f_v, u_0, v_0, width and height).

The rendering engine communicates with the tracking and calibration system via an OSC (Open Sound Control) communication [15]. This UDP protocol is fast and efficient for control commands like in this case and a variety of other software have OSC communication already implemented.

5 First Results

In a first experiment, a video projection is achieved in real time on a moving human. Figure 3 shows the reprojection of a 3D tracking information from OpenNI [12]. OpenNI library allows to extract a human silhouette from the depth map of the Kinect sensor. We use this silhouette as a blob on which the video projector will project red pixels while it projects white pixels on the background. The red blob projection follows the user in real-time regardless of the user position. The error can be seen as red edges around the background shadow of the silhouette. This error is due both to the Kinect blob which is not perfect and has a lag between the real motion and the detected movement and to the reprojection error.

In addition to user body, information of his position are projected on the ground, in front of the user. The system also works with several users and interaction information can be projected on the ground around them.

The first user reactions are positive and people are astonished by how reactive the projector is to their movements. The only lag is due to the delay of blob detection due to the Kinect sensor.

Fig. 3. Results of the projection in real time on a user

In a second experiment, a video projection is achieved on a complex 3D surface. The shadow of a 3D object is modelled and projected on the ground: in that way the shadow can artificially be moved and create an impression of illumination change. The surface is reconstructed with the RGBD camera using Kinect fusion algorithm [8]. The mesh is obtained by slightly moving the Kinect camera (figure 4) and the area to be projected is manually selected at this stage.

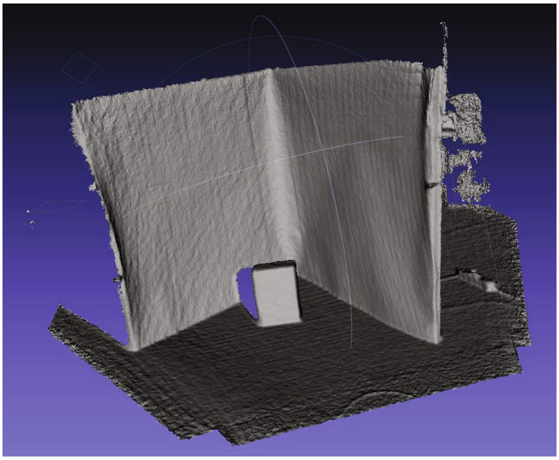

Fig. 4. Surface reconstructed with Kinect Fusion

6 Conclusion and Future Works

We have described our method for the geometric calibration of a projector and applied it to real-time projections. An application to projecting directly on a human and a novel application to projecting moving shadows on complex 3D objects were shown. Those two preliminary experiments show the feasibility of an application which uses a Kinect sensor and a classical projector to augment in real time a complex scene. An interesting scenario for those applications is in modifying in real-time the ambiance of the living room in front of a TV depending on the content displayed on the TV. Images which can be triggered by the content can be projected on objects in front of the TV or on people passing between the viewer and the TV surrounding the viewer with images.

Despite higher reprojection errors than in the state of the art of projector calibration methods, the proposed method has multiple advantages.

First, the planar surface constraint introduced by most of the state of the art techniques is removed by the combination of Heikkila's algorithm [7], the structured light and the RGBD camera. The RGBD camera simplifies the calibration process, thanks to the depth map. In the same time, the RGB sensor allows to acquire images of the projected Gray coded patterns and then, to calculate the projector to camera pixel correspondences. With this combination, the calibration can be performed on any complex surface in real time.

Second, the method is fully automated and does not require any user intervention, which is a key step towards consumer-oriented applications.

Finally, no prior knowledge about the projection surface and the projector are needed to achieve the calibration which virtually opens adaptive projections to any complex indoor scene such as living rooms.

The applications described here are preliminary and they need to be tested in several scenarios and to get more viewer feedback on the results. Also, the calibration method needs optimization to reduce reprojections errors and cameras with a faster frame rate than the Kinect will be used to reduce the delay between projection and object movements.

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